SCHEDULE-INDUCED DRINKING AS FUNCTIONS OF INTERPELLET INTERVAL AND DRAUGHT SIZE IN THE JAVA MACAQUE[1]

JOSEPH D. ALLEN AND DAN R. KENSHALO, JR.

UNIVERSITY OF GEORGIA

Three Java monkeys received food pellets that were assigned by both ascending and descending series of fixed-time schedules whose values varied between 8 and 256 seconds. The draught size dispensed by a concurrently available water-delivery tube was systematically varied between 1.0 and 0.3 milliliter per lick at various fixed-time values during the second and third series determinations. Session water intake was bitonically related to the interpellet interval and was determined by the interaction of (1) the probability of initiating a drinking bout, which fell off at the highest interpellet intervals and, (2) the size of the bout, which increased directly with increases in interpellet interval. Variations in draught size had little effect on total session intakes, but reduced bout size at draught sizes of 0.5 milliliter and below. Thus, a volume-regulation process of schedule-induced drinking operated generally at the session-intake level, but was limited to higher draught sizes at the bout level.

Key words: adjunctive behavior, fixed-time schedule, reinforcement frequency, draught size, schedule-induced polydipsia, Java monkey

When food deprived and permitted to ingest small meals delivered at spaced intervals, rats (Falk, 1961, 1969), pigeons (Shanab and Peterson, 1969), mice (Palfai, Kutscher, and Symons, 1971), and rhesus monkeys (Porter and Kenshalo, 1975; Schuster and Woods, 1966) develop excessive drinking behavior over sessions. An extended drinking bout usually follows the ingestion of each pellet, producing a pattern of postpellet drinking that has been labelled schedule-induced polydipsia (Falk, 1961).

One major factor determining the magnitude of the postpellet bout is the length of time between pellet deliveries, the interpellet interval. It has been commonly reported with rats (Bond, 1973; Falk, 1966; Flory, 1971; Keehn and Colotla, 1971; Segal, Oden, and Deadwyler, 1965) and more recently with the rhesus monkey (Allen and Kenshalo, 1976) that postpellet drinking emerges at interpellet intervals between 5 and 10 sec, increases to a maximum at intervals between 120 and 240

sec, and then declines sharply at longer intervals, describing a bitonic drinking function over the interpellet-interval continuum.

With rhesus monkeys, the bitonic water-intake functions resulted from the interaction of two component behaviors (1) the probability of initiating a drinking bout following pellet ingestion, and (2) the magnitude of the drinking bout. During an initial ascending series of interpellet intervals, the probability of initiating a postpellet bout varied bitonically, rising and then falling about a peak at an interval of 120 sec, whereas bout size systematically increased as the interpellet interval increased. Bitonic-intake functions were recovered during a subsequent descending series of intervals; however, the functional roles assumed by bout frequency and bout size were reversed, suggesting that powerful order or sequence effects were operating.

The present study systematically replicated the rhesus study using a different species of *macaque,* the Java or crab-eater, to investigate the durability and generality of the bitonic drinking function in primates and to analyze further the contribution to it assumed by sequence and order effects.

Since bout size has appeared to be systematically related to interpellet interval in a number of experimental contexts (Allen, Porter,

and Arazie, 1975; Allen and Kenshalo, 1976), the determinants of bout size regulation were also explored in the present experiment. Although the average volume of water ingested per pellet increases with interpellet interval, it is not obvious whether animals are metering the volume of intake, *per se,* or some correlate, such as the number of licks or duration of licking behavior at the spout, which results in concomitant changes in volume intake as a byproduct. Since schedule-induced drinking is not in response to a body-water deficit (indeed, it produces a substantial body-water surfeit), and since it has been shown that animals lick a cold, dry tube (Mendelson and Chillag, 1970), sometimes even in preference to water (Mendelson, Werner, and Wano, 1976), it is quite plausible that licking rather than drinking is the primary behavior induced by pellet delivery and regulated by interpellet interval. In the present study, licks at the water spout were dissociated from volume intake by systematically varying the draught size dispensed per lick at several interpellet-interval determinations.

METHOD

Subjects

Three adult male Java monkeys (*Macaca fascicularis*) all having previous experience with fixed-interval and second-order schedules of reinforcement, served. Between experimental sessions, they were individually housed in Hoeltge large-primate cages, where they had free access to water and were maintained at approximately 90% of free-feeding weights by supplementing session intakes with Purina monkey chow and mixed fruit. Experimental weights, which were 5.4 kg for Weed, 3.9 kg for Dak, and 4.1 kg for Legs, were determined twice per week.

Apparatus

Experimental sessions were conducted in Lehigh Valley primate chambers (model 1330C) with inside dimensions of 78 cm by 85 cm by 60 cm. A 7.5 cm² aperture located in the lower right-hand corner of the front panel provided access to the food magazine into which 750-mg banana-flavored Noyes pellets were dispensed. A Hoeltge drinking tube was situated 29 cm directly above the magazine and protruded 1.5 cm into the cham-

ber. Each lick on the tube activated a Skinner electric valve which, by means of an adjustable one-shot, released a calibrated draught of tap water at a regulated line pressure of 10 *p.s.i.* During the initial stage of the experiment, the draught size was set at 1.0 ml (±0.03 ml). During later stages, draught size was varied between 1.0 and 0.3 ml (±3%) by varying the operation time of the one-shot controlling the water valve.

A houselight provided continuous illumination in the chamber, and the onset of white noise signalled the start of the session. All scheduled events were achieved by solid-state circuitry which, together with recording apparatus, was located in an adjacent room.

Procedure

For the first phase of the experiment, all monkeys were subjected to an ascending series of fixed-time schedules, whereby pellets were delivered independently of any behavior every 8, 32, 64, 128, 192, and 256 sec. A brief 2-sec offset of white noise accompanied the delivery of each food pellet. Two sessions were conducted daily, the first beginning at approximately 9 a.m. and the second at approximately 4 p.m. Each session lasted until 40 pellets had been delivered. Between sessions, the monkeys were returned to their home cages. Consecutive sessions at each fixed-time schedule were conducted until total session water intakes showed no consistent changes over eight consecutive sessions.

On completion of the ascending series, a descending series of fixed-time schedules was conducted to (1) demonstrate the recoverability of intakes about the peak of the obtained drinking functions, and (2) to determine the effects of varying draught size on the drinking bout. Accordingly, Weed was returned to a fixed-time 192-sec schedule and sessions were conducted as the draught size was systematically varied through the following series: 1.0, 0.5, 0.3, 0.5, and 1.0 ml. Consecutive sessions were conducted at each draught size until session intakes showed no regular change for eight sessions. In like manner, sessions were conducted at fixed-time values of 128 and 64 sec, with draught size being manipulated in similar fashion at each schedule value.

For both Dak and Legs, the first phase was accompanied by failures to recover prior drinking values at various stages of the de-

scending series of intervals. Thus, draught-size manipulations were postponed and an attempt was made to determine the nature of the order and sequence effects that were preventing adequate recapture. The fixed-time schedule was reset to 8 sec and a second ascending series of intervals was conducted with the draught size initially fixed at 1.0 ml. Draught-size manipulations resumed at interpellet intervals of 64 and 128 sec for Dak and were conducted at the 192-sec interval only for Legs. The complete order of schedules presented to each monkey and the number of sessions required at each schedule are presented in the first two columns of Table 1.

At the end of the study, Dak was given four sessions in which 40 pellets were dispensed at a rate of one per second at the beginning of each 2-hr session. Session intake was recorded as a measure of obligatory water load produced by the ingestion of the pellets, *per se,* during a representative session length. Due to schedule complications, similar measures were not obtained from the other two monkeys.

RESULTS

Table 1 contains the sequence of FT values and draught sizes presented to each monkey, the number of sessions conducted at each, and the various drinking measures recorded during the study. The drinking measures (columns 4 to 6) are mean values averaged over the last eight sessions of each condition and constitute the data base from which the functions described in Figures 1, 3, 4, and 5 were constructed.

Figure 1 relates various drinking indices to changes in the interpellet interval. In the top panel, the milliliters of water ingested per pellet was obtained by dividing session intake (column 5, Table 1) by the number of pellets delivered (40). Bitonic functions described drinking performance during the initial ascending series for all monkeys. The functions peaked at interpellet intervals of 128 sec for Weed and Dak and at 192 sec for Legs. For Weed, the milliliter-per-pellet function was recovered about the peak during a subsequent descending series of intervals; however, the descending function for Dak was flat and greatly depressed, and a redetermination of the peak with Legs was also depressed. Bitonic

functions were recovered for these animals in a second ascending series of interpellet intervals; however, intake was generally lower than in the first series, and the location of the peak had shifted to an interval of 64 sec for Dak. Using Dak's 138.5-ml session intake at FT 1-sec as a baseline for homeostatic regulation, it can be seen from column 5 in Table 1 that session intake first exceeded the baseline at an interpellet interval of 32 sec in the first ascending series and 64 sec in the second ascending series, demarking the emergence of polydipsia. Polydipsia persisted until an interval of 192 sec in both series.

In the second panel of Figure 1, the per cent of pellets that induced a drinking bout was computed by dividing the number of intervals containing at least one lick (column 4) by the number of pellets delivered during the session (40). In the first ascending series, the resulting functions for both Weed and Legs were roughly flat and varied between 40% and 60%, until dropping abruptly at the longest interpellet interval. For Dak, however, the initial function was decidedly bitonic and peaked at a value of 95% at FT 64-sec. During the descending series, Weed's function was recovered; however, the probability of initiating a postpellet bout remained depressed and insensitive to reductions in the interpellet interval for both Dak and Legs. The original functions were recovered again during a second series of ascending intervals; however, for both monkeys drinking percentages were greatly depressed overall.

In the third panel of Figure 1, the number of milliliters ingested per bout was computed by dividing the session intake at each interpellet interval (column 5) by the corresponding number of bouts (column 6). Bout size increased monotonically with increases in interpellet interval with all monkeys. Subsequent descending- and ascending-series replications effected little change in the form of the functions but produced a slight depression in bout sizes for Weed, and slight elevations in bout size for Dak and Legs.

The ingestion rates, depicted in the bottom panel of Figure 1, were computed by dividing session intake at each interpellet interval (column 5) by the corresponding session duration in seconds (FT value × 40). Drinking rate was monotonically decreasing over the range of interpellet intervals used for Weed and Legs, and was bitonic with a rather broad peak be-

Table 1

Sequence of FT schedule and draught-size presentations to each monkey together with means of the following performance measures: total licks on the drinking tube, session water intake in milliliters, and number of pellets followed by a drinking bout. Standard deviations are in parentheses. Data represent averages of the final eight sessions of each manipulation.

Subject	Interpellet Interval (sec) (1)	Sessions (2)	Draught Size (ml) (3)	Licks (4)	Session Intake (ml) (5)	Bouts (6)
Weed				Ascending Series		
	8	8	1.0	116.6 (31.5)	116.6	21.8 (5.4)
	32	8	1.0	309.9 (95.1)	309.9	18.8 (5.7)
	64	14	1.0	400.6 (57.9)	400.6	19.1 (5.5)
	128	29	1.0	519.5 (60.6)	519.5	19.2 (3.2)
	192	12	1.0	411.6 (204.9)	411.6	16.1 (12.5)
	256	20	1.0	189.6 (71.9)	189.6	6.8 (5.5)
				Descending Series and Draught-Size Manipulation		
	192	28	1.0	302.8 (103.2)	302.8	12.5 (7.1)
	192	18	0.5	664.5 (107.9)	332.2	15.8 (4.6)
	192	14	0.3	1126.6 (88.0)	338.0	21.2 (3.0)
	192	8	0.5	810.2 (194.9)	405.1	19.1 (6.7)
	192	18	1.0	303.1 (78.6)	303.1	12.9 (4.2)
	128	12	1.0	454.1 (76.5)	454.1	23.6 (3.5)
	128	12	0.5	911.5 (106.5)	455.8	27.9 (2.9)
	128	8	0.3	1320.5 (112.9)	396.2	30.5 (5.4)
	128	10	1.0	524.0 (76.9)	524.0	28.8 (4.4)
	64	18	1.0	375.9 (54.0)	375.9	26.6 (3.2)
	64	10	0.5	670.8 (179.4)	335.4	23.8 (6.0)
	64	9	0.3	740.7 (77.9)	222.2	21.8 (3.1)
	64	14	1.0	338.6 (46.5)	338.6	18.6 (3.9)
Dak				Ascending Series		
	8	8	1.0	0 (0)	0	0 (0)
	32	8	1.0	154.6 (60.4)	154.6	34.9 (6.4)
	64	16	1.0	308.5 (47.9)	308.5	37.9 (2.4)
	128	11	1.0	401.9 (73.6)	401.9	29.6 (6.8)
	192	18	1.0	124.2 (62.1)	124.2	10.2 (3.8)
	256	8	1.0	104.6 (54.6)	104.6	8.0 (3.5)
				Descending Series with Draught-Size Manipulation		
	192	10	1.0	92.8 (46.9)	92.8	7.9 (3.2)
	192	14	0.5	221.5 (70.0)	110.8	8.0 (2.4)
	192	30	0.3	396.5 (89.6)	119.0	12.4 (4.8)
	192	9	0.5	233.9 (75.7)	116.9	9.2 (2.5)
	192	8	1.0	120.0 (40.3)	120.0	5.9 (1.4)
	128	12	1.0	115.1 (51.9)	115.1	7.1 (4.1)
	64	12	1.0	151.5 (76.8)	151.5	10.2 (3.3)
				Second Ascending Series with Draught-Size Manipulation		
	8	8	1.0	7.6 (7.2)	7.6	0.8 (0.5)
	32	8	1.0	61.1 (34.2)	61.1	7.0 (4.2)
	64	42	1.0	263.9 (136.2)	263.9	24.8 (12.7)
	64	8	0.5	441.6 (138.5)	220.8	30.9 (9.4)
	64	14	0.3	471.0 (149.6)	141.3	27.2 (5.7)
	64	8	1.0	216.9 (68.1)	216.9	18.6 (4.7)
	128	18	1.0	157.6 (50.8)	157.6	11.5 (4.5)
	128	12	0.5	131.2 (73.7)	65.6	9.2 (5.6)
	128	8	0.3	1097.1 (147.3)	329.1	31.0 (4.5)
	128	8	0.75	143.4 (131.5)	107.6	7.6 (2.8)
	128	8	1.0	295.2 (158.8)	295.2	21.4 (10.5)

Table 1 *continued*

Subject	Interpellet Interval (sec) (1)	Sessions (2)	Draught Size (ml) (3)	Licks (4)	Session Intake (ml) (5)	Bouts (6)
			Baseline Water Intake			
Dak (cont)	1	4	1.0		138.5 (63.9)	
Legs			Ascending Series			
	8	8	1.0	80.1 (19.1)	80.1	17.1 (3.3)
	32	8	1.0	126.9 (42.0)	126.9	12.5 (3.5)
	64	14	1.0	215.2 (33.8)	215.2	12.2 (2.3)
	128	13	1.0	399.1 (27.6)	399.1	18.6 (3.2)
	192	15	1.0	480.2 (121.3)	480.2	19.4 (4.2)
	256	12	1.0	223.4 (87.6)	223.4	7.5 (2.6)
			Descending Series			
	192	16	1.0	287.6 (53.6)	287.6	9.6 (2.2)
			Second Ascending Series with Draught-Size Manipulation			
	8	9	1.0	67.4 (58.0)	67.4	7.9 (6.1)
	32	8	1.0	92.5 (55.1)	92.5	4.8 (1.5)
	64	36	1.0	68.1 (19.8)	68.1	3.2 (0.7)
	128	19	1.0	131.1 (42.5)	131.3	5.9 (2.0)
	192	14	1.0	234.5 (90.8)	234.5	8.6 (4.5)
	192	14	0.5	423.8 (140.6)	211.9	13.4 (2.9)
	192	11	0.3	1483.7 (501.3)	445.1	24.2 (8.3)
	192	8	0.75	514.9 (43.7)	386.2	16.6 (2.3)
	192	8	1.0	427.9 (83.0)	427.9	17.2 (3.0)

tween interpellet intervals of 32 and 128 sec for Dak. The forms of the various initial series functions were recovered with subsequent descending and ascending series.

Figure 2 provides a quantitative description of how drinking was distributed into consecutive fourths of the interpellet interval as the interval size varied. For all monkeys, drinking initially peaked in the last quarter of the shortest interval that induced drinking. Progressive increases in the interpellet interval from that point resulted in systematic shifts of maximal drinking to earlier quarters of the interval so that by FT 128-sec, drinking bouts were nearly confined to the first half of the interval for two of the three monkeys. The drinking distributions for Dak were the broadest of the three; however, at FT 256-sec the majority of Dak's drinking also occurred during the first half of the interval.

The degree to which the monkeys regulated the size of the drinking bout as draught size varied is depicted several ways in Figure 3. In the left column, the milliliters ingested per bout, calculated by dividing session intake (column 5, Table 1) by the number of bouts (column 6) is plotted as a function of the volume dispensed per lick with FT values as the

parameter. The functions produced by Weed were the most orderly, and were fairly descriptive of those produced by the other two monkeys. Bout size was not constant, but decreased systematically as draught size was reduced from 1.0 to 0.3 ml. This relation was independent of the FT schedule. The FT schedule, in turn, influenced bout size independently of draught size, with longer interpellet intervals being associated with larger bouts.

To evaluate the degree to which bout size fit a volumetric *versus* a lick-output regulatory model, the bout sizes have been replotted in the right column of Figure 3 as percentages of the mean milliliters per bout produced by the 1.0-ml draught size. Were the locus of points clustered about the horizontal, iso-volume function, it would demonstrate that monkeys varied their lick output in an inverse proportion to changes in draught size so as to conserve the volume of the postpellet bout; points clustered about the diagonal, iso-lick function, would indicate that monkeys reduced the bout volume in direct proportion to decreases in draught size, so as to conserve the number of licks per postpellet bout. As may be seen in the right column of Figure 3, neither outcome generally obtained. With the exception of the
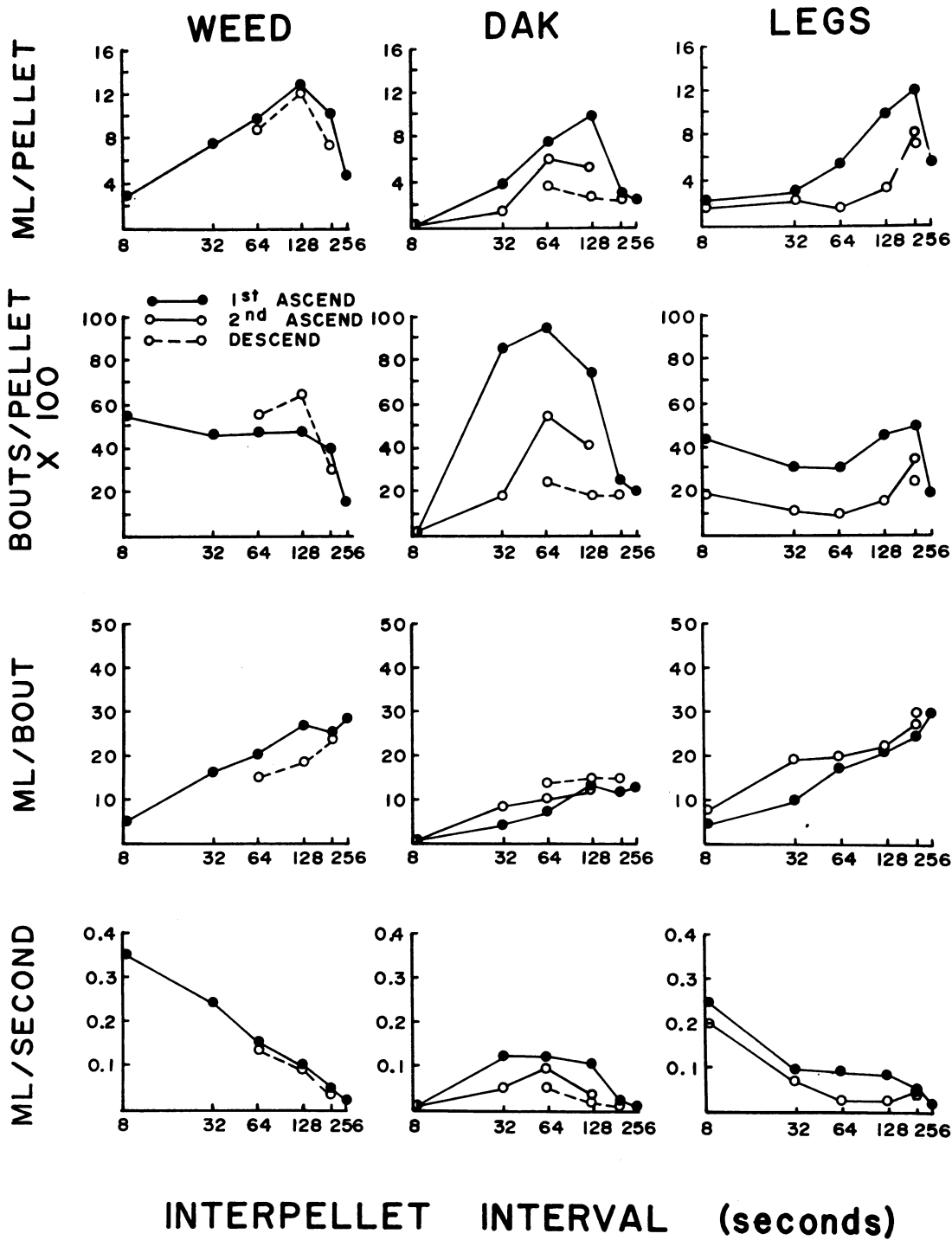
Fig. 1. First panel: milliliters ingested per pellet as a function of interpellet interval in seconds during first ascending (filled circles), descending (open circles, dashed lines), and second ascending series (open circles, solid lines). The x-axis is logarithmic for compact presentation. Second panel: per cent of intervals containing a drinking bout. Third panel: milliliters of water ingested per drinking bout. Fourth panel: Ingestion rate in milliliters per second.
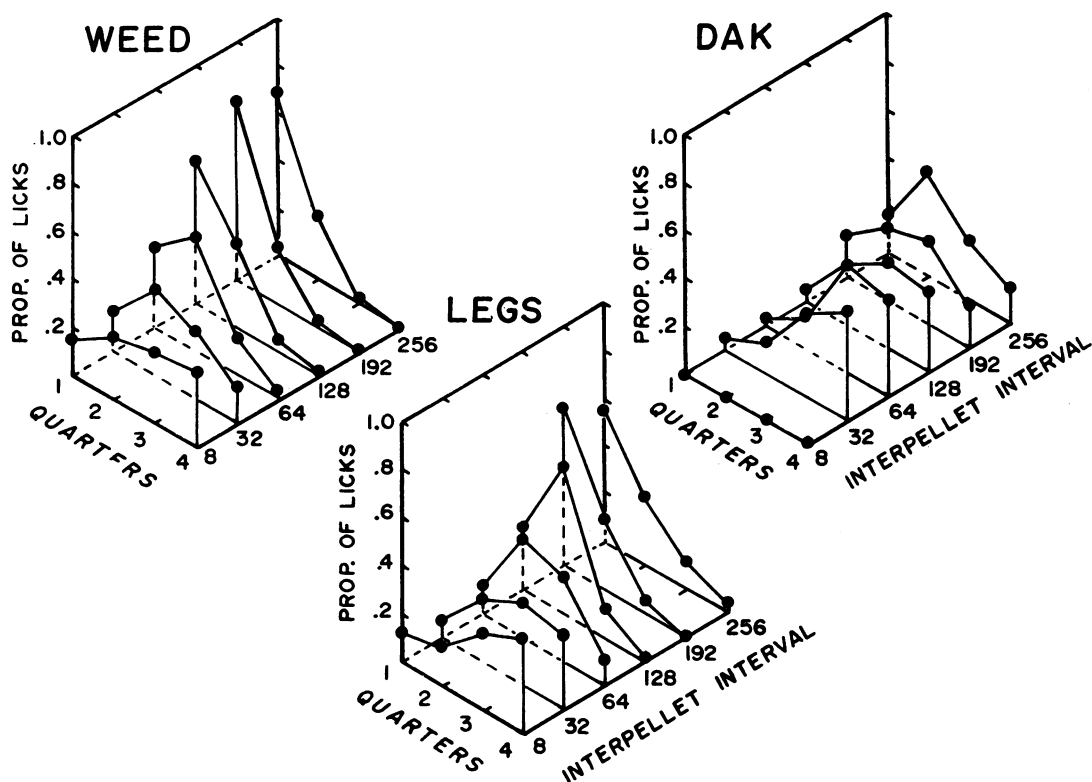
Fig. 2. The proportion of total session licks distributed into consecutive fourths of the interpellet interval. A family of curves relating these distributions to the first ascending interpellet interval series is arrayed from front to back.

two points at 0.75-ml draught size, relative intakes were distributed within the area between the iso-volume and iso-lick functions in every monkey. Weed's data were again the most orderly and suggested that bout size may systematically depart from volume regulation and approach lick-output regulation as draught size diminishes; however, the functions produced by the other two monkeys fail to bear out this relationship consistently.

Figure 4 presents total session intakes (column 5, Table 1), bouts (column 6), and licks (column 4) as functions of draught size with interpellet interval as the parameter. The session-intake functions in the left column exhibited variability among monkeys and among interpellet intervals within monkeys; however, overall they did not vary systematically with changes in draught size. The number of bouts initiated per session, in the middle column, increased slightly but systematically in each monkey as draught size was reduced from 1.0 to 0.3 ml; the number of licks on the tube, in

the right column, increased markedly with similar changes in draught size.

DISCUSSION

The bitonic milliliter-per-pellet functions in the first panel of Figure 1 are representative in form of those typically produced by rats and similar in degree to those produced by rhesus monkeys (Allen and Kenshalo, 1976). At their peaks, one rhesus monkey consumed 18.7 ml per pellet and the other 13.4 ml per pellet; whereas Weed, Legs, and Dak ingested 13, 12, and 10 ml per pellet at their respective peaks, even though their body weights were only one-third to one-half of those of the rhesus. In fact, if polydipsia were to be expressed in terms of water-to-food intake ratios, it becomes apparent that this ratio is relatively independent of both the size of the animal and size of the pellet. For example, at FT 128-sec, which produced maximal drinking, Weed
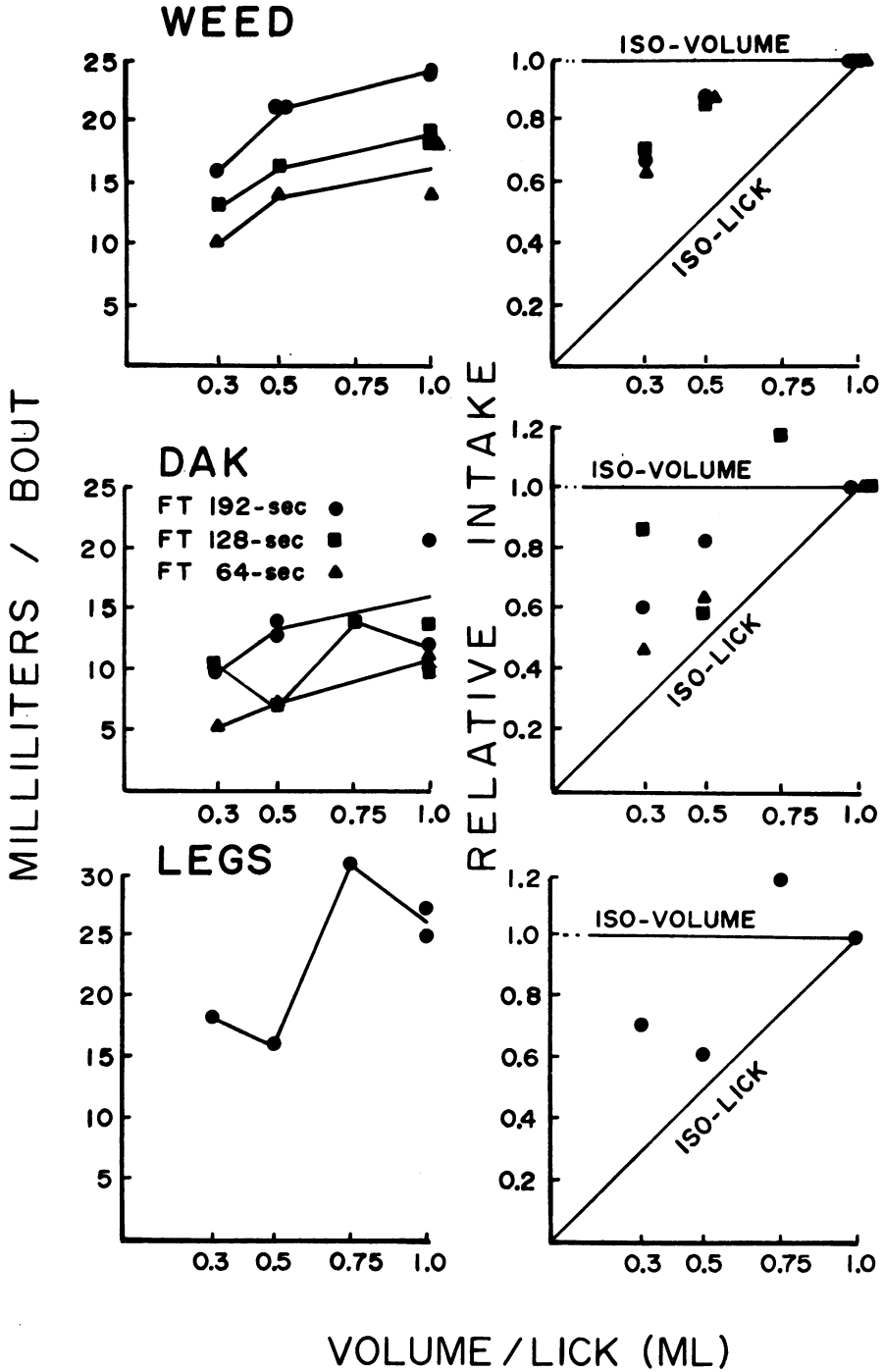
Fig. 3. Left column: milliliters ingested per bout plotted as a function of draught size with interpellet interval as a parameter. Values from all determinations are presented and functions intersect the midpoints of multiple determinations. Right column: relative intake per bout plotted as a function of draught size with interpellet interval as a parameter. Intake at the standard 1-ml draught size for each FT valve was used to compute relative intakes for other draught sizes at each FT valve, and multiple determinations at each draught size were averaged. Iso-volume (horizontal line) and iso-lick (major diagonal line) functions are also presented. See text for details.
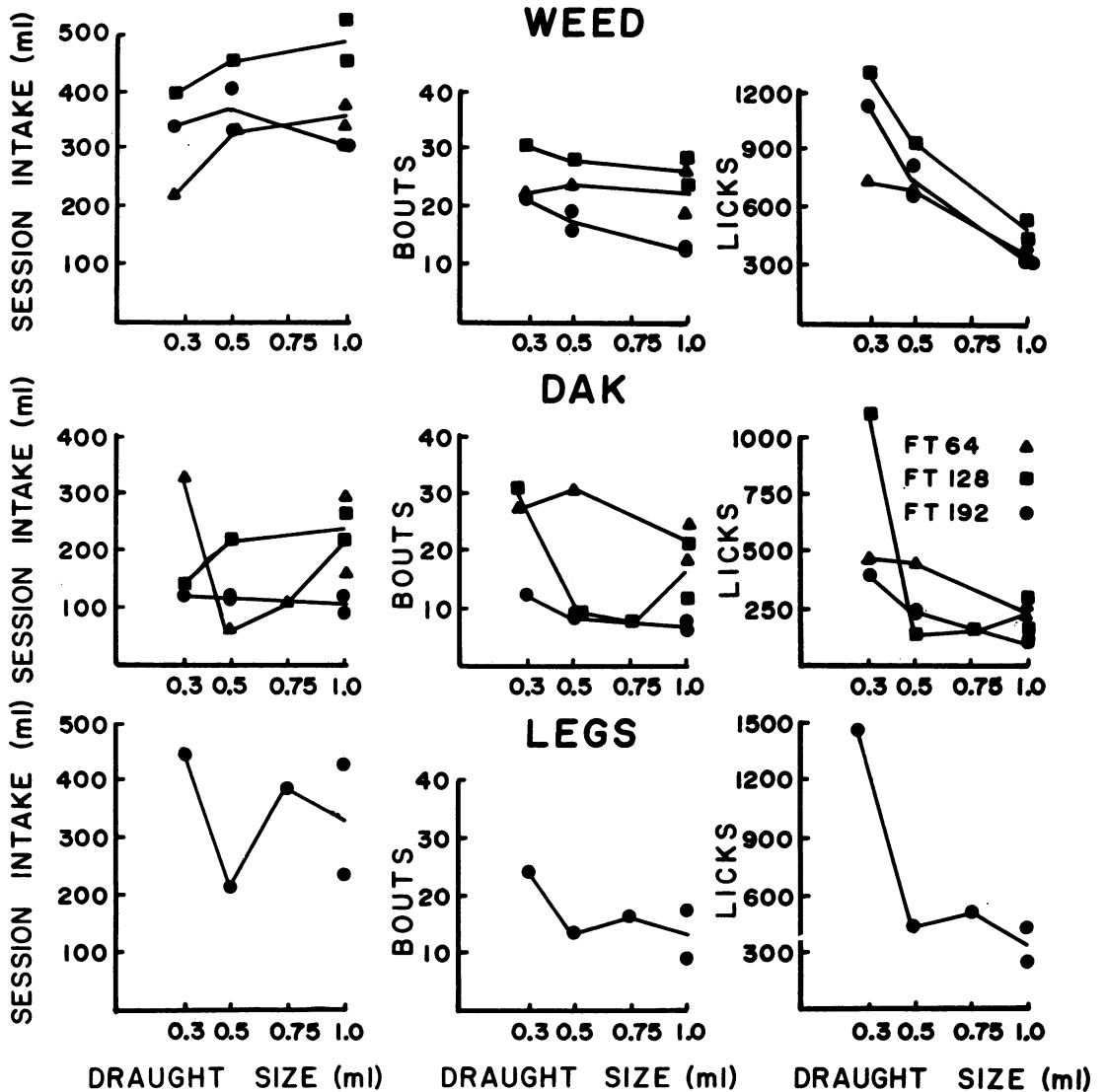
Fig. 4. Left column: session water intake plotted as a function of draught size with interpellet interval as the parameter. Values from all determinations are presented and functions intersect the midpoints of multiple determinations. Middle column: the number of drinking bouts initiated per session as a function of draught size with interpellet interval as the parameter. Right column: The number of licks on the tube per session as a function of draught size, with interpellet interval as the parameter.

ingested 519.5 ml of water and 30 g of 750-mg food pellets, yielding a water-to-food ratio of 17.3 ml per gram. Dak and Legs, at their respective peaks, ingested 13.4 and 16.0 ml per gram respectively. These ratios are consistent with those of rhesus monkeys working for 750-mg food pellets on FI 128-sec schedules (24.9 to 17.9 ml/g) and with ratios determined from Flory (1971) with rats that pressed for 45-mg pellets on an identical schedule ($\overline{X}$ = 18.9 ml/g; Range = 20.6 to 16.5 ml/g).

The bitonic functions representing milliliters ingested per pellet were the resultant interaction of changes in the probability of bout initiation and bout size as interpellet interval varied. The monotonically rising bout-size functions (third panel, Figure 1) were fairly consistent among animals and were typical of those produced by rhesus monkeys. However, functions describing changes in the probability of bout initiation were quite variable among monkeys, and were similar only at the

upper range of interpellet intervals, where the probability of drinking fell sharply for each monkey. Only the function produced by Dak closely approximated the bitonic "inverse-U" form reported earlier for rhesus monkeys and for rats (Keehn and Colotla, 1971; Segal, Oden, and Deadwyler, 1965). It would appear that, in general, increases in bout size are primarily responsible for the ascending segment of the bitonic water-intake gradient, whereas the steep decline in bout probability at interpellet intervals greater than 2 min is solely responsible for the descending segment of the gradient. The peak in the function represents the turning point along the interpellet-interval parameter in relative contribution supplied by these two component processes, in the Java macaque.

Attempts to replicate the first ascending-series function with subsequent descending and ascending series revealed marked order and sequence effects in two of the three monkeys. Successful replication was obtained in one monkey, Weed, but even its second water-intake function was the product of elevated drinking probability and lowered bout-size functions which, in this case, cancelled each other out. For the other two monkeys, drinking probability was suppressed in the second and third series to a greater extent than bout size was elevated, resulting in overall suppression in session intake similar to that reported previously with rhesus *macaques* (Allen and Kenshalo, 1976). During the descending series of intervals, Dak's drinking-probability function was flat and apparently locked at the percentage obtained at the final interpellet interval in the ascending series, a sequence effect that also occurred with rhesus monkeys. The function could be unlocked by returning the monkey to a short interpellet interval and initiating a second ascending series. The second ascending-series functions were quite similar in form to those of the first ascending series for both monkeys, demonstrating that the flatness of the functions during the intervening descending series was determined by the sequence with which the intervals were presented. However, all replications of the first-series functions were generally suppressed, indicating an additional order effect.

Why drinking probability in a monkey is differentially sensitive to direction of change in the interpellet interval is not clear. Were the sequence effect the result of differential sensitivity on the part of the animal to decreasing *versus* increasing intervals, one might argue that it did not receive sufficient exposure to the descending series of interpellet intervals. However, Dak received 71 sessions to the first interpellet interval in the descending series followed by a total of 24 additional sessions to the remaining two shorter intervals. Since more total sessions were devoted to the three intervals comprising the descending series (95) than were devoted to the entire six intervals comprising the initial ascending series (69), it is unlikely that differential sensitivity to the two sequences was involved.

It is interesting that in each animal, deviations in bout probability from the first to the remaining series of determinations were always associated with opposite changes in bout size; when bout probability was lowered, as with Dak and Legs, bout size increased, and *vice versa* with Weed. It would appear that the reciprocal relation previously reported between these two measures (Allen and Kenshalo, 1976) is reliable and may be caused by the influence that changes in drinking probability exert on the resulting interval between successive drinking bouts, or interbout interval. The interbout interval is jointly determined by the scheduled interpellet interval, which fixes the minimal interval between drinking occasions, and the proportion of intervals in which a bout is actually initiated. Since previous research has shown that increases in interbout interval, whether produced directly by removing access to the water tube during interpellet intervals (Allen and Porter, 1976; Porter and Allen, 1977), or indirectly by stretching the interpellet interval (Allen, Porter and Arazie, 1975), result in increases in bout size, it is plausible that the obtained interbout interval is a more direct determinant of bout size than is the interpellet interval. If so, expressing the milliliter-per-bout functions in Figure 1 in terms of the interbout interval should improve the orderliness of the plotted functions. First, order and sequence effects should shrink or disappear altogether, and second, the fit to a linear regression line should improve.

In Figure 5, the milliliter-per-bout functions for the Java monkeys have been replotted in terms of the obtained mean interbout interval, computed by dividing the number of bouts (column 6, Table 1) by the total session time,
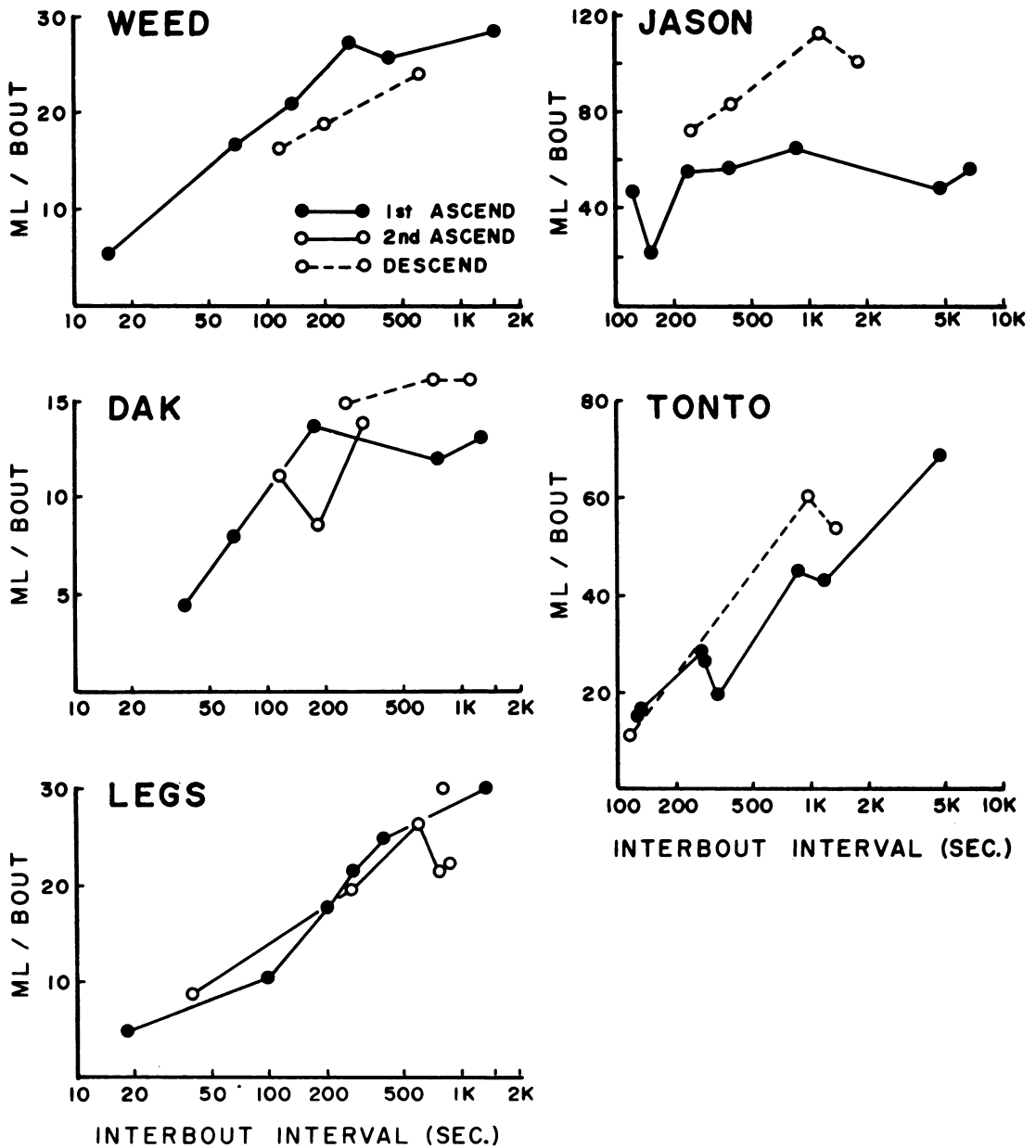
Fig. 5. Milliliters ingested per bout plotted as a function of the obtained interbout interval for the first ascend-
ing (closed circles), the second ascending (open circles, solid lines), and the descending (open circles, dashed lines)
series determinations. Data for Weed, Dak, and Legs are presented together with those of two rhesus *macaques*,
Jason and Tonto, in an earlier study (Allen and Kenshalo, 1976).

and are presented with similar transformations
for the rhesus monkeys in the previous study
(Allen and Kenshalo, 1976). The separate as-
cending and descending series functions have
converged into one function for four of the
five monkeys. A clear separation between Ja-
son's ascending and descending functions is
still apparent, although it is slightly reduced.

Dramatic improvements in fit to a linear re-
gression were produced in the transformed
functions for two of the five monkeys. The per
cent of variance unaccounted for $(1\text{-}r^2)$ was re-
duced from 48 to 10% for Tonto and from 51
to 38% for Dak when bout size was related to
log interbout interval rather than log inter-
pellet interval. The unaccounted for variance

did not vary much for two other monkeys, Legs and Jason, and increased from 14 to 28% for Weed. On balance, it would appear that bout size is more directly determined by the obtained interbout interval.

Another and independent determinant of bout size is the draught size. The two variables appear to be directly correlated, as increases in the volume per lick produced increases in the milliliters ingested per bout. As indicated by the relative intake functions in Figure 3, drinking at the bout level was not strictly regulated by either a volume-intake or a lick-output process at the lower draught sizes, but rather appeared to reflect a compromise between them. Only with the two monkeys receiving both 0.75- and 1.0-ml draught sizes did volume regulation appear to obtain, and then only between these two draught sizes. Had Weed, who produced the clearest functions, been presented with the 0.75-ml draught, a clearer picture might have emerged, where bout size conformed to a volume regulation model only at the higher draught sizes between 1.0 and 0.75 ml and departed systematically from volume regulation as draught size fell below 0.75 ml.

Volume regulation appears to be approximated more closely with total session intake, where intake functions, though variable both within and among monkeys, were flatter than bout-size functions over the draught size parameter. The flatter session intake functions resulted from the fact that decreases in bout size were partially compensated by a corresponding increase in bout probability. That is, as smaller draught sizes systematically reduced the size of each bout, they also increased the number of bouts initiated during the session.

For purposes of model building, it is important to determine whether variations in bout size and bout probability were necessarily interdependent or were independent of each other in producing stable session intakes. As draught size decreased, the number of licks in a bout could have approached the temporal constraints of the interpellet interval, thus forcing an increase in bout frequency to ensure session volume regulation. This did not occur. Intra-interval drinking distributions produced by different draught sizes did not vary systematically from those produced by the standard 1.0-ml draught at each inter-

pellet interval tested. A glance at these drinking distributions (Figure 2) reveals that at no interval did licking persist throughout the interval. Therefore, it would appear that bout size and bout probability are functionally separable processes.

These data bear importantly on recent findings of volume regulation during schedule-induced drinking in the rat. Freed, Mendelson, and Bramble (1976) reported volume regulation of session intake and, in a more extensive experiment (Freed and Mendelson, 1977), volume regulation of the individual bout size as drinking rate was varied. When a drinking tube with a 2.6-mm diameter orifice was replaced by a tube with a 1.0-ml orifice, causing a mean reduction in drinking rate from 30 to 16 ul/sec, animals increased their bout duration proportionately and preserved bout size. While reducing the flow rate through a drinking tube by constricting its orifice is not an identical operation to reducing the volume of discretely presented draughts, both place similar constraints on the rate or efficiency of ingestion.

Our data thus provide a systematic replication of volume regulation at the session level, but impose limitations on this process at the bout level. Monkeys do not regulate bout size when draught size falls below 0.5 ml. Whether a similar function holds with the rat is not determinable from the Freed *et al.* studies, since only two drinking rates were used. The issue bears on the vitality of contemporary volume-correlated (Freed, Zec, and Mendelson, 1977) and lick-correlated feedback (Wayner, 1974) explanations of schedule-induced drinking; however, the answer awaits careful parametric investigation.

REFERENCES

Allen, J. D. and Kenshalo, D. R., Jr. Schedule-induced drinking as a function of interreinforcement interval in the rhesus monkey. *Journal of the Experimental Analysis of Behavior*, 1976, **26**, 257-267.

Allen, J. D. and Porter, J. H. Demonstration of behavioral contrast with adjunctive drinking. *Physiology and Behavior*, 1975, **15**, 511-515.

Allen, J. D., Porter, J. H., and Arazie, R. Schedule-induced drinking as a function of percentage reinforcement. *Journal of the Experimental Analysis of Behavior*, 1975, **23**, 223-232.

Bond, N. Schedule-induced polydipsia as a function of the consummatory rate. *The Psychological Record*, 1973, **23**, 377-383.

Falk, J. L. Production of polydipsia in normal rats by an intermittent food schedule. *Science,* 1961, **133,** 195-196.

Falk, J. L. Schedule-induced polydipsia as a function of fixed-interval length. *Journal of the Experimental Analysis of Behavior,* 1966, **9,** 37-39.

Falk, J. L. Conditions producing psychogenic polydipsia in animals. *Annals of the New York Academy of Sciences,* 1969, **157,** 569-593.

Flory, R. K. The control of schedule-induced polydipsia: frequency and magnitude of reinforcement. *Learning and Motivation,* 1971, **2,** 215-227.

Freed, W. J. and Mendelson, J. Water-intake volume regulation in the rat: schedule-induced drinking compared with water-deprivation-induced drinking. *Journal of Comparative and Physiological Psychology.* 1977, **91,** 564-573.

Freed, W. J., Mendelson, J., and Bramble, J. M. Intake-volume regulation during schedule-induced polydipsia in rats. *Behavioral Biology,* 1976, **16,** 245-250.

Freed, W. J., Zec, R. F., and Mendelson, J. Schedule-induced polydipsia: the role of orolingual factors and a new hypothesis. In J. Weijnen and J. Mendelson (Eds), *Drinking behavior: oral stimulation, reinforcement and preference.* New York: Plenum, 1977. Pp. 341-397.

Keehn, J. D. and Colotla, V. A. Schedule-induced drinking as a function of interpellet interval. *Psychonomic Science,* 1971, **23,** 69-71.

Mendelson, J. and Chillag, D. Schedule-induced air licking in rats. *Physiology and Behavior,* 1970, **5,** 535-537.

Mendelson, J., Werner, J. S., and Wano, M. Schedule-induced cold-licking, but not drinking, in guinea pigs. *Bulletin of the Psychonomic Society.* 1976, **8,** 237. (Abstract)

Palfai, T., Kutscher, C. L., and Symons, J. P. Schedule-induced polydipsia in the mouse. *Physiology and Behavior,* 1971, **6,** 461-462.

Porter, J. H. and Allen, J. D. Schedule-induced polydipsia contrast in the rat. *Animal Learning and Behavior,* 1977, **5,** 184-192.

Porter, J. H. and Kenshalo, D. R. Schedule-induced drinking following omission of reinforcement in the rhesus monkey. *Physiology and Behavior,* 1974, **12,** 1075-1077.

Schuster, C. R. and Woods, J. H. Schedule-induced polydipsia in the rhesus monkey. *Psychological Reports,* 1966, **19,** 823-828.

Segal, E. F., Oden, D. L., and Deadwyler, S. A. Determinants of polydipsia: IV. free-reinforcement schedules. *Psychonomic Science,* 1965, **3,** 11-12.

Shanab, M. E. and Peterson, J. L. Polydipsia in the pigeon. *Psychonomic Science,* 1969, **15,** 51-52.

Wayner, M. J. Specificity of behavioral regulation. *Physiology and Behavior,* 1974, **12,** 851-869.